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THE CAVERNS AND PEOPLE OF NORTHERN YUCATAN

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The northern part of the Yucatan Peninsula, instead of having the luxuriant tropical vegetation often found in countries of low latitude, is in reality a great semi-arid plain. The forests, nowhere dense, dwindle away in parts to a stunted "brush" barely supported by the scanty soil which only partially covers the underlying limestone rock. It is, indeed, to the porous character of this rock and the absence of pronounced relief, rather than to a deficiency in the rainfall, that the aridity must be chiefly ascribed. The porous, fissured limestone rock is like a thirsty sponge which soaks in the water with only less avidity than the hot sands of a desert. Under these circumstances, it is of interest to note that, before the Discovery, this region supported probably the highest civilization of the western hemisphere, and that the conditions of human occupancy at the present time are not wholly unfavorable.*

The great plain of northern Yucatan extends southward from the Gulf of Mexico as a gentle, even slope, at an average increase in elevation of about one foot per mile. To the northward it sinks almost as gradually under the surface of the sea, forming the great Yucatan Bank with a width of some 100 miles, beyond which it

* The writer's personal knowledge of the country has been gained from a trip made early in 1904, the principal object being the collection of zoölogical materials and data. The work was in the interests of the Museum of Comparative Zoölogy at Cambridge, and consisted of a stay of several weeks at Progreso, a few days at Merida and Izamal, and nearly two months at Chichen-Itza.

sinks rapidly to the great depths of the Gulf. There are no harbors on the coast and the shoal water of the Bank makes it necessary for large steamers to anchor some miles off shore, whence freight and passengers are carried back and forth by lighters. Steamers must be ever in readiness to seek deeper water upon the approach of one of the dreaded "northers," those fierce storms that sweep from our southern states across the Gulf and down upon the unprotected coast. The coast itself is low, and, for 170 miles, skirted by a narrow sand reef, behind which lies an extensive lagoon of brackish water, which is called "el rio" and "la cienaga," and which opens to the sea at the west. At only two or three places along the entire reef do tidal inlets occur.*

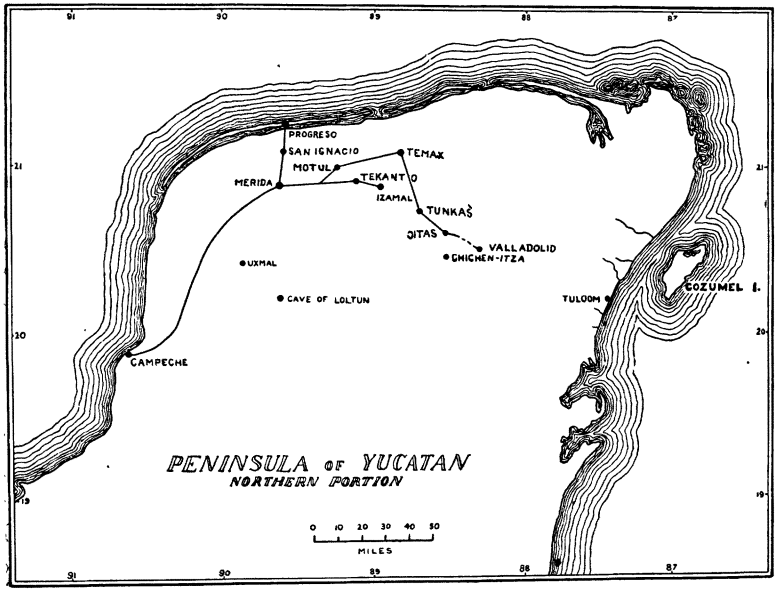


FIG. I.

By the courtesy of the Museum of Comparative Zoölogy, Cambridge.

To the southward of Merida, about 50 miles from the sea, the land rises in the form of a series of low hills, locally known as the "sierra," which have a general trend from northwest to southeast. Their average height is 400 or 500 feet. According to Mr. E. H. Thompson, in the neigrborhood of Xul, they reach a greater elevation of nearly 900 feet (Heilprin, 1892, p. 136). The extent of

* The method of formation of this coastal strip of sand and the consequent lagoon has been ably discussed by Schott (1866).

this range of "mountains" to the southeastward is not accurately known.

At San Ignacio, about half way between Merida and the coast, the general surface appears to be almost as flat and level as a floor; and here one may look for miles, with almost unobstructed view, across the enormous plantations of henequen, the plant which supplies the "sisal" fiber of commerce, and which constitutes one of the greatest sources of wealth in Yucatan. South of Merida, however, the dissection of the plain has progressed further, and the

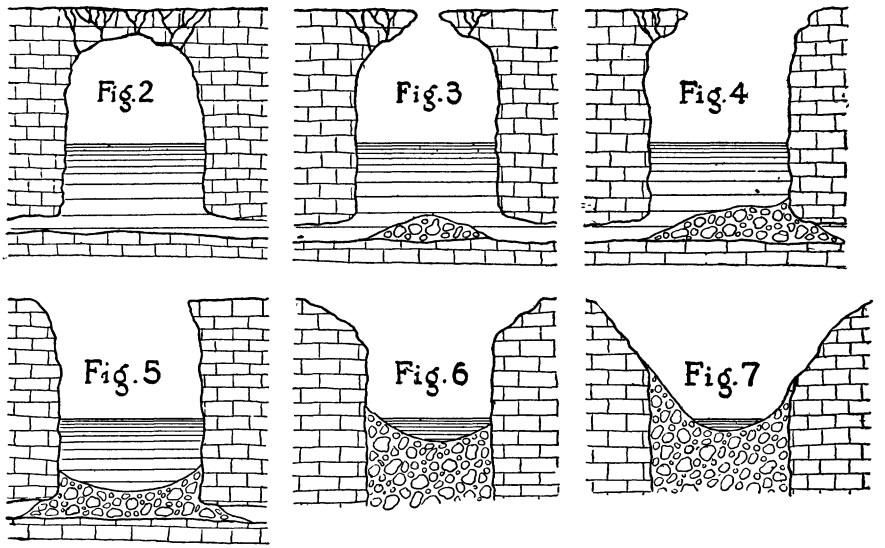


FIG. 2—Dome-shaped cavern, the roof of which has not yet fallen in; 3. A later stage in which the middle of the roof has given way; 4. Most of the roof has given way, but a portion still remains; 5. The typical cenote with vertical walls (see Fig. 7); 6. A later stage in which the walls are being worn back; 7. A topographically old cenote or "aguada" resembling a kettle-hole with a pool at the bottom.

surface topography is much more irregular. On account of the porosity and fissured surface of the limestone that constitutes the country rock, the heavy rains of the wet season cut irregular channels or "arroyas," whose positions are dependent upon the local conditions; but nowhere are these of any great length or permanency. For it should be understood that nowhere in the whole northern half of this great peninsula are there rivers or permanent surface streams, with the exception of a few short ones on the eastern coast; and these, as will be shown later, were probably underground streams whose roofs have fallen in. But in certain parts of the country

there are more or less permanent pools or "aguadas," and water is also to be found in deep caverns and sink holes. Many of the latter are of a peculiar chimney-like structure, and are known as "cenotes." It is with the nature of this underground drainage that the remainder of this paper will be chiefly concerned.

The rainy season in Yucatan is from about July to October. During the rest of the year the rainfall is small, though there may be occasional heavy thunder showers. In all parts of the country, the surface water quickly finds its way underground, and in the hill region it has formed many caverns and subterranean passages, which, if we may judge from the descriptions of those who have explored them, are similar in most respects to the caverns of any elevated limestone region. There is one peculiarity, however, which appears to be rather characteristic of the Yucatan karst, and that is the prevailing vertical character of the underground caverns. In the lower north country horizontal tunnels appear to be entirely absent, or at least very unusual; in the caverns of the hill region they do occur, but are very limited in comparison with such caverns as the Mammoth Cave in Kentucky. In the neighborhood of San Ignacio, between Merida and the coast, are to be found numerous small, round, vertical, shaft-like holes which remind one forcibly of glacial moulins.

The Cenotes

"Cenote" was the name given by the ancient Mayas to the deep waterholes or sinks of Yucatan; and since the character of these peculiar sinks appears to be distinctive, it may be well to retain the name, especially for the deep, circular, vertical-walled holes, without lateral passages, which may be considered as the type of the mature form. Varieties are to be found in the topographically younger dome-shaped caverns, with roofs intact, and the mature "aguadas" with sloping sides.

In presenting what the writer believes to be the most plausible explanation of the somewhat unusual features of Yucatan hydrography, it may be well first to describe what may be taken as the typical cenote, and then by other examples to illustrate their probable cycle of development.

The two well-known cenotes at Chichen-Itza may be taken as examples of what we may consider as typical. But although these have been so long known, and so often described, it is surprising how inaccurate are most of the dimensions that have been given.

The larger of these is known as the Sacred or Sacrificial Cenote because of the fact that, according to legend, and as has recently been confirmed by dredgings, it was a part of the Mayan religious ceremonies to cast into this deep pool human sacrifices who were to intercede with the gods of water for a plentiful supply of that much-needed element. This cenote is nearly circular in outline, with a diameter of 190 feet, while its walls, which are in places vertical, and locally overhanging, are 65 feet high from the level of the water to the general surface of the ground above. It is thus like a great circular shaft or stone quarry with a pool of water at the bottom. This water, which is fresh, is 36 feet deep and occupies the whole diameter of the shaft except at one point where there is a narrow beach. Its dark greenish color is not due, as stated by many, to its depth, nor to the overhanging vegetation, but rather to the microscopic algæ which grow in it. While the side walls have been spoken of as vertical, they are not straight and smooth, but are

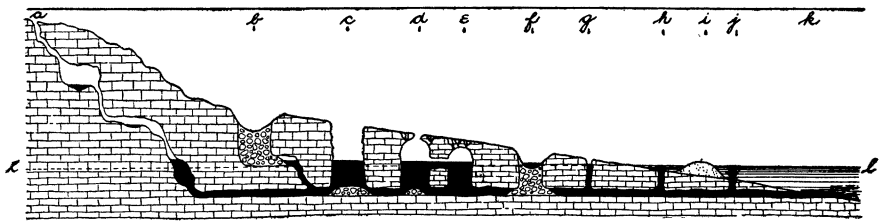


FIG. 8—Schematic North-south section from the "sierra" to the coast illustrating types of cenotes and caverns, relations of water level, subterranean connections, etc. *a*. Hill cavern, with long passages and pools of water held in impervious depressions; *b*. An old age cenote ("holla") holding water only temporary after rains; *c*. Typical cenote (see Figs. 5 and 9); *d* and *e*. Young cenotes or dome-shaped caverns (see Figs. 2 and 3) connected by a passage at water level; *f*. Old age cenote with permanent pool of water ("aguada," see Fig. 7); *g*. Water-hole near the coast, when water level is very near the surface; *h*. Fresh-water spring in a brackish lagoon or "cienaga"; *i*. Coastal sand reef on which coastal towns are located; *j*. Fresh-water spring a short distance from shore; *k*. Gulf of Mexico; *l*. Sea level.

composed rather of a series of projecting ledges apparently due to the varying hardness of the slightly northward-dipping strata. Figure 4 is a diagrammatic section of such a cenote.

The so-called Great Cenote has in reality a somewhat smaller diameter at the water surface than the other, but it appears larger because of its sloping walls. The walls are, however, except on one side, practically perpendicular for a considerable distance from the water, above which they slope back until they attain the ground level (Fig. 5). On one side there are remains of a ruined stairway; for it was this cenote which supplied the inhabitants of the ancient city of Chichen-Itza with water.

An examination of some of the other cenotes in the vicinity of Chichen-Itza and elsewhere, furnished an explanation of the mode of origin. At Pisté, a small Indian village but a short distance from Chichen-Itza, the village well, after going a few feet through solid rock, opens out into a large cavern with water at the bottom. The depth to water appears to be about the same as in the cenotes at Chichen, and, as nearly as could be judged, the diameter also approaches similar dimensions. Here, then, we apparently have a cenote which is entirely roofed over, the well above mentioned being artificial. This condition may be represented by the diagram in Figure 2.

About three miles east of Chichen is a cenote known as the Ikil. This was apparently, at one time, like that at Pisté, but the roof over the greater portion of it has fallen in, leaving at present a partial roof over two sides. Here again advantage had been taken of the overhanging roof to construct a well for drawing water. Figure 3 may be taken to represent a section of the Ikil cenote as in an intermediate stage of development in which only the central part of the roof, the top of the dome, has collapsed. There is a story that in the plaza of a certain Yucatan town a horse and rider once disappeared suddenly from sight by the breaking in of the roof of one of these subterranean caverns. Whether or not that story can be credited, Dr. Gaumer, long resident at Izamal, is authority for the fact that workmen, in digging a well at Motul, broke through the top of a great dome-shaped cavern and lost their tools. Many wells in Yucatan are thus situated over underground caverns.

There can apparently be little doubt that these peculiar water holes were formed, in the first place, by the solution of the rock, so as to make great underground dome-shaped caverns. The surface rock, as is common in limestone regions, is much harder than that below. The water therefore makes its way down through crevices in the resistant upper layer causing comparatively little solution; but when it encounters the softer strata below, its solvent power is exercised and large caverns with roofs intact are the result. In the walls of the Sacred Cenote at Chichen some of the lower strata are so soft that the rock can be crumbled in the hand almost like dust. The essentially horizontal position of the strata may be another important factor in giving the cenotes their vertical walls and few horizontal passages. The dip of the strata is so slight that it has probably been easier for the water to work its way directly down than to run off laterally. Either by the too great extension

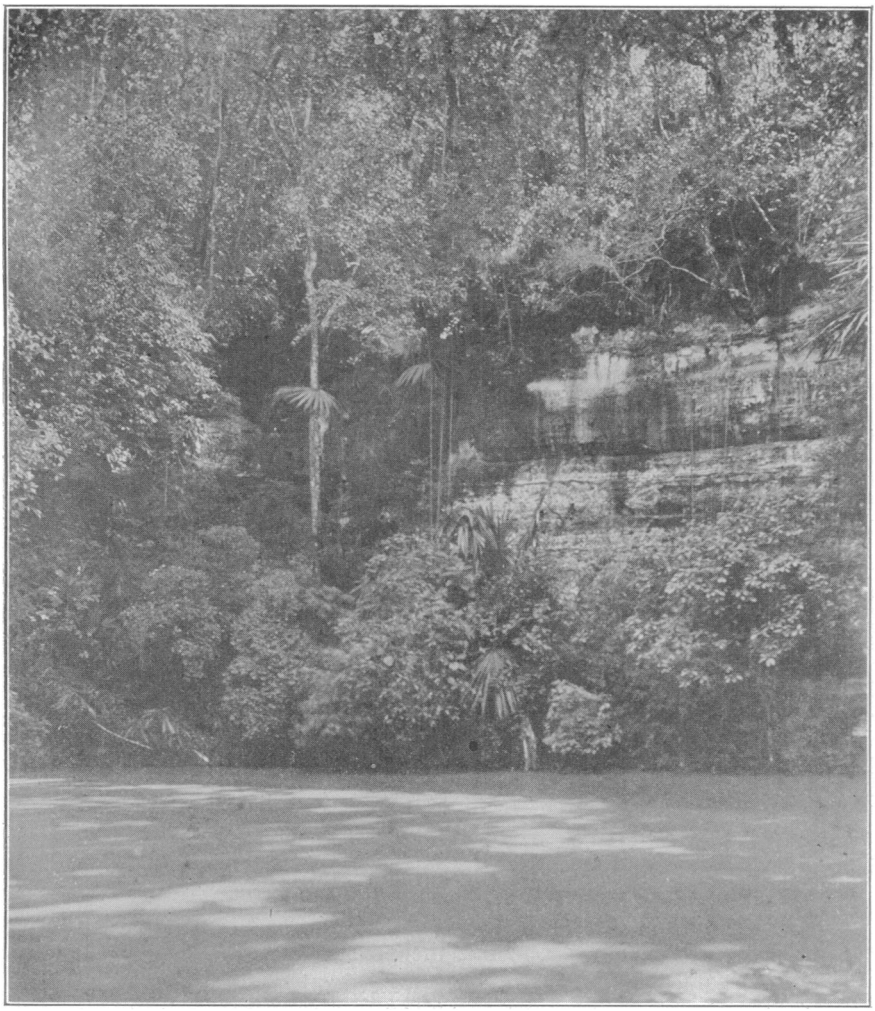
of the cavern or by the gradual sapping of the roof, the latter eventually collapses, and the cenotes, such as have been described, are the result. One has but to witness the effects of a heavy tropical thunder storm upon the steep walls of one of these cenotes to realize how important an agent is erosion in their subsequent development; and considering the number of stones that go rolling down even during a brief storm, it seems strange that the walls are not worn back faster. They wear back first at the top, the lower part of the wall

FIG. 9—The Sacred or Sacrificial Cenote at Chichen-Itza. (Photo by E. H. Thompson.)

remaining vertical (Fig. 6); but the process of wear is continued until the cenote consists of a pool of water at the bottom of a funnel- or basin-like depression (Fig. 7). The twin cenotes of Shkolak (Xcolac) and Skashek, about two-thirds of the way from Izamal to Tunkas, would appear, according to the descriptions of Baker (1895) and Charnay (1887), to belong to this stage. In some cases the bottoms appear to have become entirely filled in, and such depressions then hold water only temporarily after rains.

The Underground Drainage

There appears to be a common belief in Yucatan that the water which sinks into the rock gathers into well defined subter-



(Fig. 10—The Great cenote at Chichen-Itza. Owing to the wearing back of the walls, the vegetation has better access to the water and is more luxuriant. (Photo by E. H. Thompson.)

ranean rivers, which in turn empty into the sea. The reasons brought forward in support of this view may be briefly summarized.*

* Many of the facts and ideas here expressed are on the authority of Dr. G. F. Gaumer, an American physician who has for many years resided in Izamal.

In the first place, it is to be noted that the water in the cenotes is fresh and sweet as a rule, and it is argued that if they were not in some way connected with underground streams it would become stagnant and foul. It should be borne in mind, however, that in many countries, even in the tropics, water is often stored in cisterns for long periods and remains reasonably sweet. Another argument is that the water level in the cenotes remains fairly constant, having only minor fluctuations corresponding with periods of rainfall and drought, showing that the waters must have a ready escape. Cases are known in which neighboring cenotes are actually connected, the connection being in some cases (as at Motul) below the surface of the water.

Boys have sometimes thrown in gourds and hats, which have later been recovered from another well. In 1900 a domestic duck fell into a well (which opens into a subterranean cavern) at Izamal, and the following day was taken out of a well some one-fourth mile to the north. Izamal is probably situated over a great subterranean river; a line of important towns can be picked out which mark its course from the southern hills to the Gulf.*

Further evidence of subterranean streams is furnished by the numerous "boiling" springs along the north coast. Many of these open into the coastal lagoon while others open out in the salt waters of the Gulf itself. This water bubbles up from the bottom of the "cienaga" through holes from 6 to 15 feet in diameter, in which the sand is constantly agitated. Ober (1884) states that a fresh water spring in the Atlantic has long been known off St. Augustine, Florida, and quotes Humboldt as follows, regarding their occurrence on the Yucatan coast:

> On the northern coast of Yucatan, at the mouth of the Rio Lagartos, 400 meters from the shore, springs of fresh water spout up from amidst the salt water. It is probable that from some strong, hydrostatical pression the fresh water, after bursting through the banks of calcareous rocks between the clefts of which it has flowed, rises above the level of the salt water.

As Ober says, Florida and Yucatan are of similar geological formation, which may account for the appearance of these springs on the coasts of both peninsulas.†

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* On the authority of Dr. Gaumer.

† Ballou ("Due South, or Cuba past and present") wrote in 1885 that much of the drinking water, and certainly the best in use at Nassau, as well as at some of the neighboring islands, was procured from fresh water springs bubbling up through the salt water. He says the same is true also on the shores of the Persian Gulf. In the former case, the water was brought to the surface through barrels filled with sand, while in the Persian Gulf divers go down with leather bags which they open over the bubbling fresh water springs at the bottom. Hitchcock (1905) mentions fresh water springs in the ocean on the volcanic shores of the Hawaiian Islands.

The coastal springs mark the mouths of underground rivers, and the villages in their vicinity are the terminal ones of the lines that mark the courses of the streams from the hills to the sea. The inhabitants of these coastal villages, in some cases, place hollow tree trunks in the holes of the sea floor through which the water gushes, thus leading it to the surface of the Gulf without commingling with the salt water. They, in this way, obtain their supply of fresh water by going out on the Gulf in canoes! During times of storm, when the Gulf is too rough for canoes, it is necessary to go inland

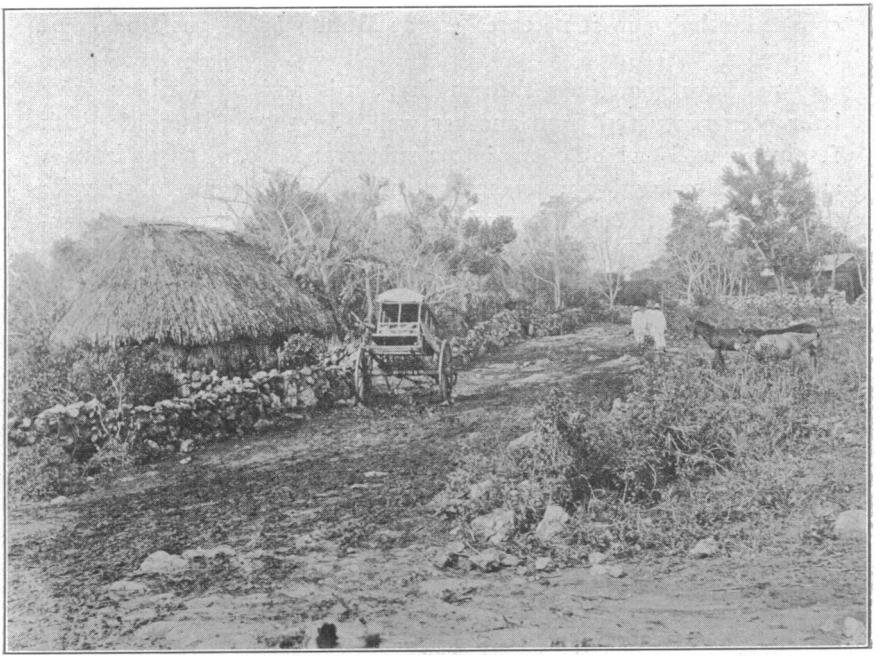

FIG. 11—Scene in Citas, a village 30 miles north of Chichen-Itza. Shows scanty soil and characteristic vegetation. (Photo by E. H. Thompson.)

a mile or more across the "cienaga" to get fresh water. All the towns along the north coast, except Progreso, are said to be located where these subterranean streams open.

At Ascension Bay, on the east coast of the Yucatan peninsula, one of these rivers, 30 feet wide, has its roof broken in for about a mile inland, and, for this distance, runs between vertical walls not over three feet high. This probably represents the type of drainage in all the peninsula, merely differing in the fact that the roof of the once subterranean stream has here given way.

Another noticeable fact is that in most and possibly all of the cenotes in the more northern part of the peninsula the water stands at a common level. The available data as to altitudes and depths of the cenotes to water level are so incomplete and inaccurate that a consistent table cannot at present be prepared; but the bulk of the evidence seems to indicate that, in all of those cenotes north of the

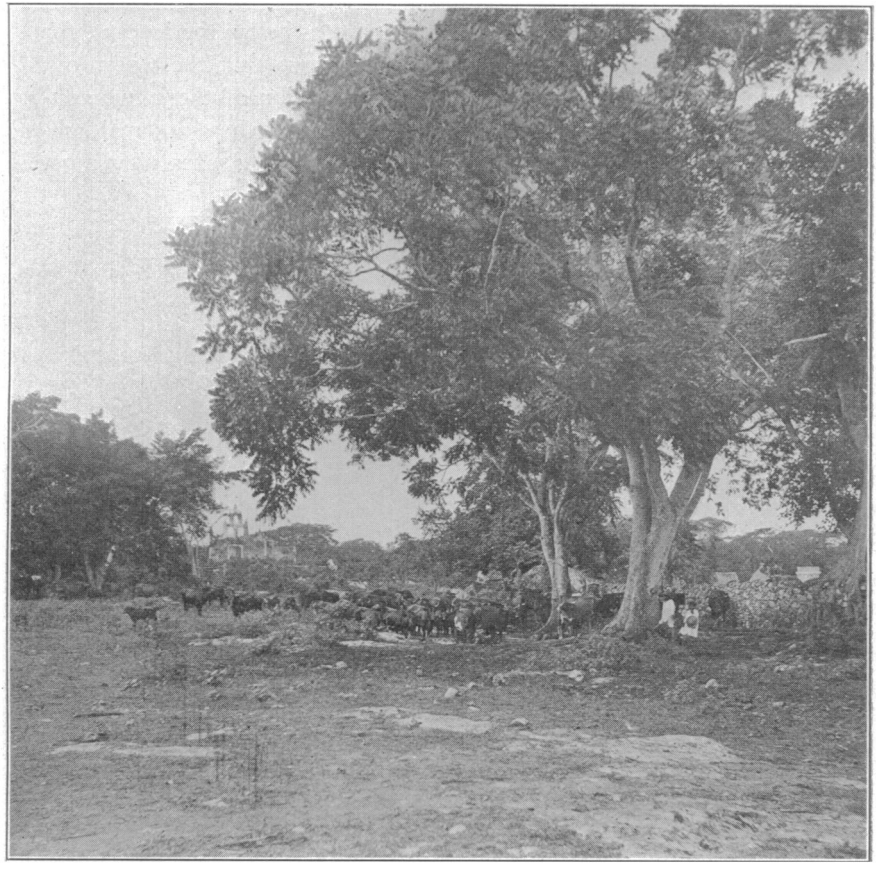

FIG. 12—Scene in front of the "hacienda" at Chichen-Itza. (Photo by E. H. Thompson.)

"sierra," the water stands at a level only a little above that of the Gulf. The land surface rises on an average of about a foot to the mile and, making allowance for local irregularities, the distance in feet from the surface to the water level, at any particular point, is approximately the distance of that place from the Gulf in miles. Thus we find that close to the coast the water lies very near the

surface. Merida is 25 miles from the coast; according to Schott (1866), and Heilprin (1892), its altitude is 28 to 30 feet, and, on the testimony of the same authors, the water in the cenotes is some 26 to 30 feet below the surface. Other striking cases of agreement might be adduced, but these will suffice to illustrate the point.

There are two ways in which we may account for the maintenance of such a condition of the karst water. Either there are connecting passages between the different cenotes below the level of the sea, or else the rock at that level is so porous that the water can traverse it easily, or there may be a combination of these two conditions. Some of the evidence for believing that these are real subterranean streams has been given above. Against such a view must

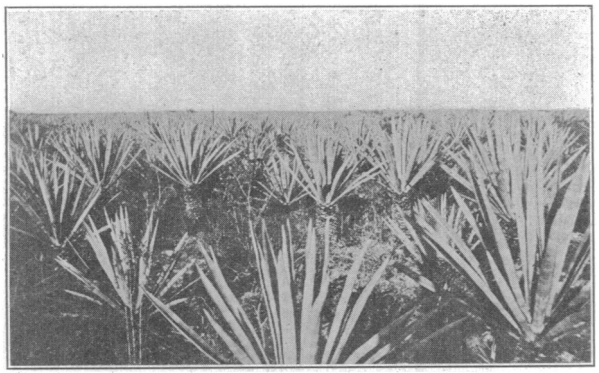

FIG. 13—Henequen plantation at San Ignacio. (Photo by L. J. Cole.)

be put the fact that in two cenotes only some three miles or so apart, entirely different species of catfishes were found living, although the general conditions seemed much the same. In one of the cenotes, however (the Sacred Cenote), the water was only 36 feet deep, while in the other (the Ikil) a sounding line was lowered to 95 feet below the water surface! Such being the case, there can be no doubt that extensive subsidence has taken place in the Yucatan peninsula since its principal drainage features were formed; for in no other way can we account for the great depth of this cenote below the level of the sea. At one time the land must have stood at least 95 feet higher than it does to-day. At that time, the drainage conditions were probably similar to those found in any ordinary limestone region, with long horizontal tunnels and caverns, some distance above sea level, and vertical shafts leading down to them. Subse-

quent subsidence carried the horizontal passages below sea level, thus gradually raising the level of the water in the vertical shafts, but maintaining practically the same height all over the peninsula.

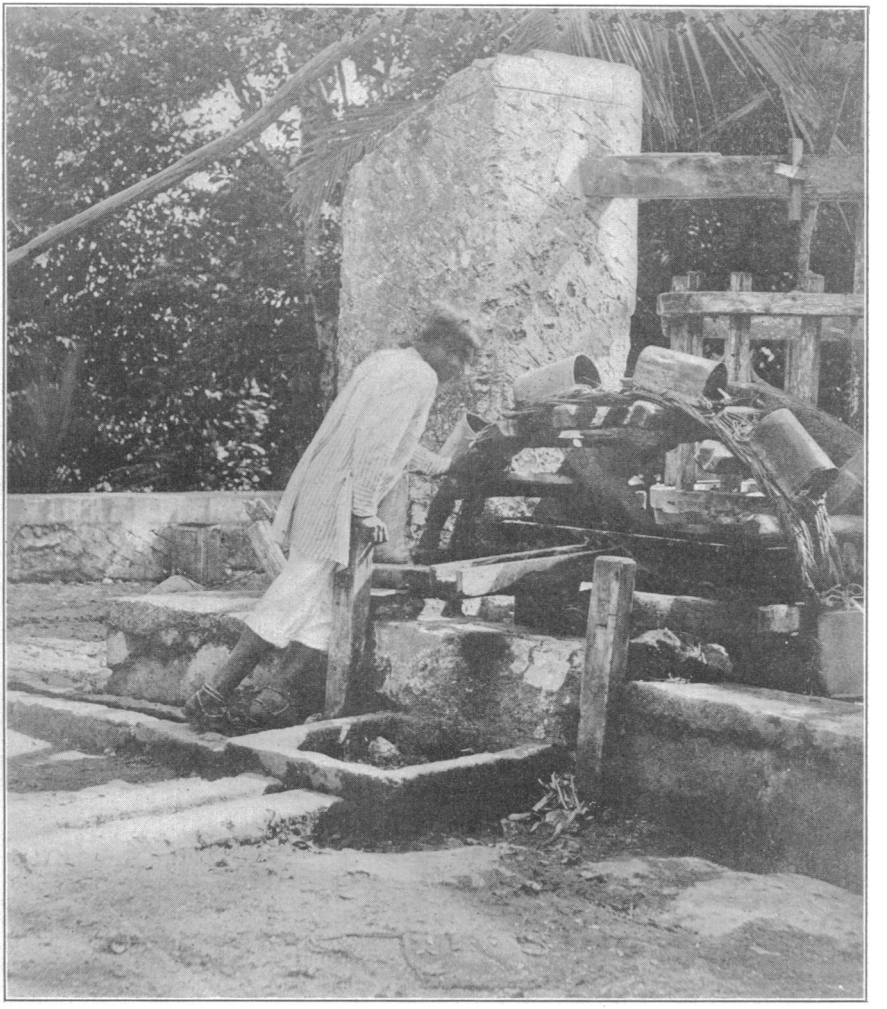

FIG. 14—A native wheel, with buckets, for drawing water. (Photo by E. J. Thompson.)

While it is possible, then, that there exist actual underground rivers, they are in most cases more than that, for they are actually below the level of the sea as well, and are to be looked upon as connecting tunnels completely filled with water rather than as real

streams. There were, however, undoubtedly in some cases, horizontal passages at higher levels, which might not yet be entirely "drowned," and which would account for the transportation of floating objects such as hats, etc., as already described. In other cases no doubt the caving in of the roofs and the accumulation of débris has blocked the passages from many of the cenotes, the water now having to make its way out by seepage. This would account for the comparatively shallow water in some of them, and also the restricted distribution of certain species of fishes.

In the hill region the drainage system is still largely above the sea level, and it here presents the features more commonly associated with limestone caverns. Here there are more lateral passages that can be traversed, but though, here and there, water may stand in impervious pools, the lower levels appear to be practically coincident with that of the sea. In Figure 8 an attempt has been made, by a schematic north-and-south cross-section from the hill region to the Gulf, to represent the principal features of the Yucatan karst which have been so briefly outlined.

Relation of Hydrographic Conditions to People

The natural semi-aridity of northern Yucatan is accentuated by the fact that the soil covering the rock is in many places very scanty. The semi-arid quality is especially marked during the day season, when many of the trees lose their leaves and the general appearance of the forests reminds one strongly of our own forests in early spring or late fall; and many of the native birds migrate to the southward from the peninsula, just as many of our birds go south (some of them to Yucatan) during the winter months.* The failure of the soil to retain moisture also limits very closely the kinds of crops that can be cultivated successfully. It is true that during the rainy season many garden crops may be grown successfully, but the two most important products of the country are corn and henequen. Sugar cane is cultivated to some extent. The raising of cattle is limited by the scarcity of forage, while the leaves of certain trees have to be gathered for the horses in place of hay.†

As to the corn and henequen, the former is all consumed in the country, the latter is practically all exported as the crude fiber. The method of raising corn employed by the natives is dependent upon

* Some evidence for such a migration has been presented by the author (Cole, 1906, p. 112) in the introduction to a paper on the birds of Yucatan.

† The stock can be turned loose and does not have to be herded during the day. It cannot get to the water in the cenotes, and consequently has to return to the tanks in the corral.

the weather conditions, and is very impoverishing to the soil. At the close of the dry season, the Indian prepares his "milpa" or cornfield by burning the timber from a tract of land, which is then planted in corn when the rains begin. A good crop is dependent upon plenty of rain. Corn is the staple food and a scarcity of this cereal, due to a bad season, is a serious matter to those living at a distance from the towns.

Henequen is grown on the dry, deforested plains, especially of the northwestern section. It is the staple product of the country, and the demand for it, created by the shutting off of the supply of manila fiber from the Philippines during the Spanish-American war, returned princely fortunes to the class of Yucatecans who own the enormous henequen plantations. As a consequence Merida is a city of life and gaiety, and has been referred to as the Paris of America.

There seems to be no evidence for believing that the climatic conditions in Yucatan were any different at the time the Maya civilization was at its height than they are to-day, and it seems remarkable that so high a state of culture and civilization should have arisen under conditions which seem in many ways so unfavorable.

Although it is believed that the ancient Mayas built reservoirs for the storage of water, they apparently did not know how to dig wells to obtain it. It is accordingly found that all their important cities were situated where there was access to the aguadas and cenotes, or to the caverns of the hills, the floors of some of which have been worn smooth by the generations of bare feet that have gone down into their depths and toiled back with the day's supply of water. Mention has been made of the fact that, on the northern coast, the villages are located in intimate relation to the supplies of fresh water. With the advent of the Spaniard came a knowledge of well digging. It is said that good water may be obtained by sinking a well almost anywhere. In ancient times the water was brought up by hand; later it was drawn from the wells by ropes and buckets; and sometimes, at the deeper wells mules were employed for hauling it up; but now windmills have been introduced, and as there is usually plenty of wind, these do the work economically and well. The city of Merida and vicinity is, when viewed from a slight elevation, a veritable forest of steel windmills of American make.

The dry climate of Yucatan, with its cool nights, has a decided influence on the conditions affecting health. It is much healthier

than most countries lying so well within the tropics, and lacks almost entirely the terrors of the "tierra caliente" of Mexico proper. Yellow fever is endemic, it is true, but apparently has seldom or never been very prevalent, and Casares (1906) is authority for the statement that it has now "been almost completely expelled." The fishes in the cenotes and larger pools keep the mosquito larvæ largely exterminated there, and a little systematic effort would do much to exterminate them in the temporary pools of water which are held in hollows in the rock for a few days after a rain, and which are quickly taken advantage of as breeding sites by the mosquitoes. In certain regions, where there are open aguadas, malaria and dengue fever are a serious menace, especially to foreigners; but here, also, a consistent crusade against the mosquitoes would undoubtedly better conditions. This should be comparatively easy in a karst country where the greater part of the water quickly disappears underground.

Literature

Baker, Frank C. 1895.—A Naturalist in Mexico, being a visit to Cuba, Northern Yucatan, and Mexico. Chicago, 145 pp.

Ballou, Maturin M. 1885.—Due South, or Cuba Past and Present. Houghton, Mifflin and Co., Boston and New York, 8°, ix + 316 pp.

Charnay, Désiré. 1887.—The Ancient Cities of the New World. Being voyages and explorations in Mexico and Central America from 1857-1882. Translated from the French. New York, xiv + 514 pp.

Casares, David. 1906.—A Notice of Yucatan, with some remarks on its water supply. *Proc.* Amer. Antiquarian Soc. for 1905, new ser., vol. 17, pp. 207-230.

Cole, Leon J. 1906.—Aves. In "Vertebrata from Yucatan," by Leon J. Cole, Glover M. Allen, and Thomas Barbour. *Bull.* Mus. Com. Zoöl., vol. 50, No. 5, pp. 101-159, pls. 1 & 2.

Heilprin, Angelo. 1892.—Geological Researches in Yucatan. Proc. *Phil.* Acad. Nat. Sci. for 1891, pp. 136-158.

Hitchcock, C. H. 1905.—Freshwater Springs in the Ocean. *Pop. Sci. Mon.,* vol. 57, No. 8, pp. 673-683.

Ober, Frederick A. 1884.—Travels in Mexico and Life Among the Mexicans. Boston, 672 pp.

Schott, Arthur. 1866.—Die Küstenbildung des nordlichen Yucatan. *Pet. Geog. Mitt.,* vol. 12, pp. 127-130.